Electron Cooler for
Low-Energy RHIC Operation

December 3, 2009

Near-term goals

FY10:

- **Start regular physics and engineering meetings**
- **Choose one design (with or without solenoids)**

- **Decide about undulators**
- **Design realistic beam transport**
- **Design appropriate bending magnets**
- **Address many physics and engineering questions**

mid FY10:

- **Start architectural design**

late FY10:

- **Start electrical design**
- **Start mechanical design**

bi-weekly, Thursday, 11a.m.-noon, until better time is available

Projection of needed C-AD labor force is available (see also ECOOL meeting 11/19/09)

Meeting agenda

- Baseline parameters
- Outstanding physics questions
- Outstanding engineering questions

Electron Cooler

Present baseline option:

Recycler's Pelletron (FNAL) – 6MV electrostatic electron accelerator

main components:

1) pressure vessel

2) high-voltage insulating support structure

3) charging system

4) accelerating/decelerating tubes

Covers full energy range of interest:

Electron kinetic energies

0.9-5MeV (for ions beam energies 2.5-10GeV/n)

Location in RHIC tunnel

Considered locations: IR4, IR10, IR12.

Selected:

IR4

Two options for IR4 exist.

Will need to select preferred option in order to proceed with architectural design of blockhouse for Pelletron.

Issues for IR4

Option#1:

1) Steep slope

dirt will be removed to make flat road access

2) need to assemble Pelletron over the cryo lines

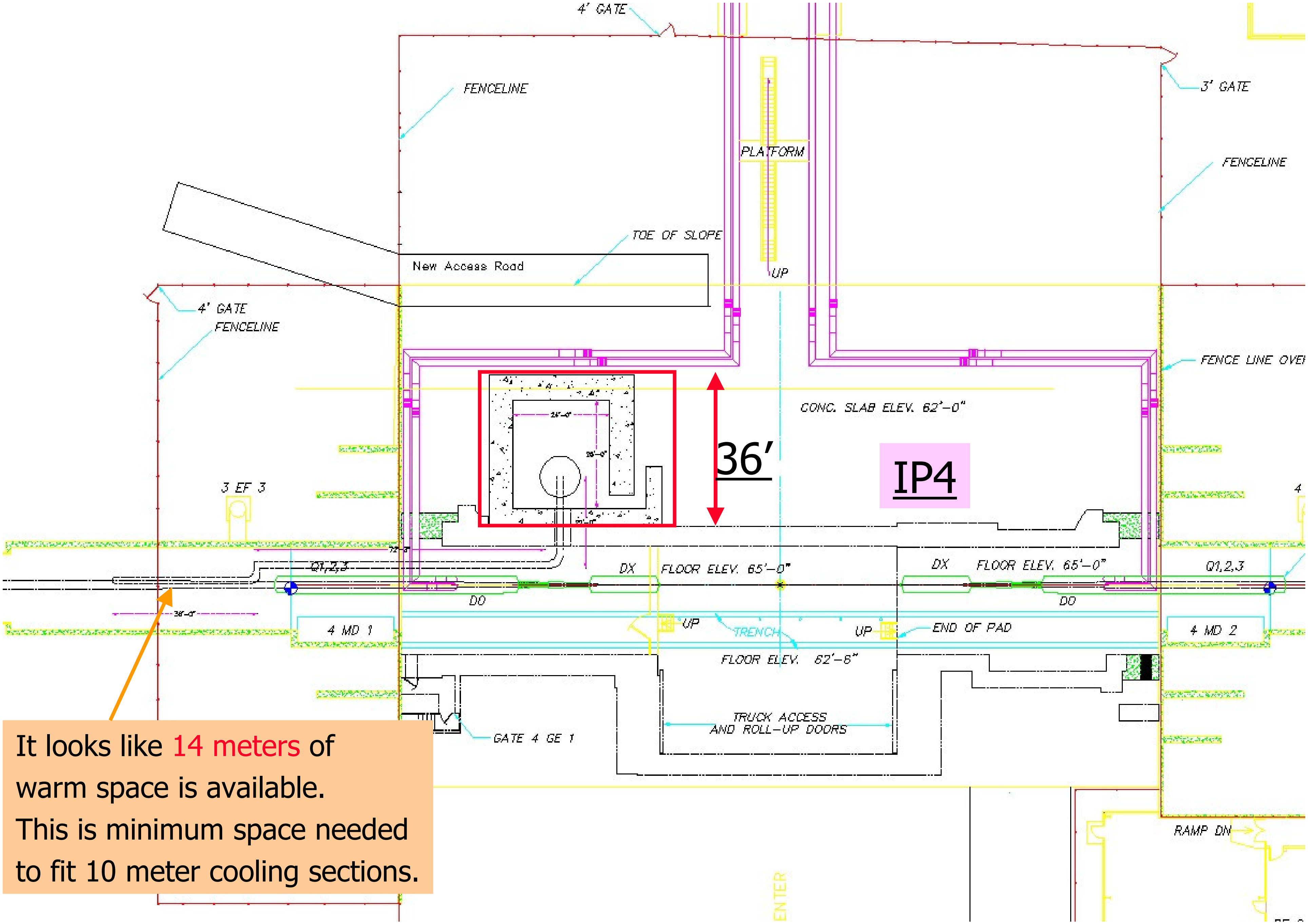
it was done before and should not be a problem

3) Building of blockhouse should be done during RHIC shutdown, since this area is behind the fence. But once Pelletron is installed one can move the fence to allow access to blockhouse during RHIC operation.

Option#2: Blockhouse can be assembled outside cryo pipes:

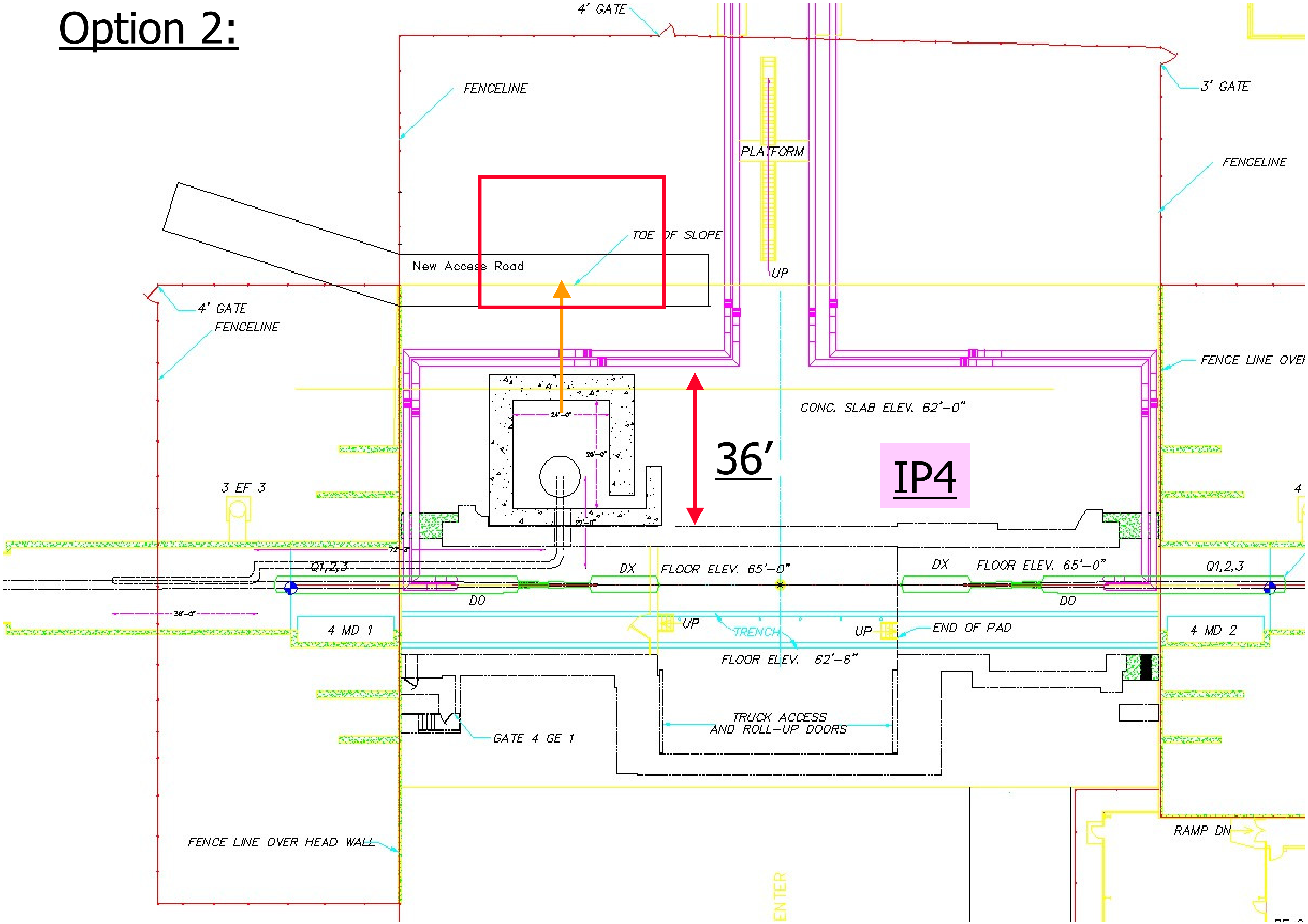
- this makes longer beam transport by 36'
- but allows assembly during RHIC operation; easier access.

- construction during RHIC operation?



It looks like 14 meters of warm space is available.
This is minimum space needed to fit 10 meter cooling sections.

Option 2:



4' GATE
FENCELINE
PLATFORM
3' GATE
FENCELINE
TOE OF SLOPE
New Access Road
UP
4' GATE
FENCELINE
FENCE LINE OVER
CONC. SLAB ELEV. 62'-0"
36'
IP4
3 EF 3
Q1,2,3
DX
FLOOR ELEV. 65'-0"
DX
FLOOR ELEV. 65'-0"
Q1,2,3
DO
DO
4 MD 1
UP
TRENCH
UP
END OF PAD
4 MD 2
FLOOR ELEV. 62'-6"
TRUCK ACCESS
AND ROLL-UP DOORS
GATE 4 GE 1
FENCE LINE OVER HEAD WALL
RAMP DN

RHIC Electron Cooler parameters

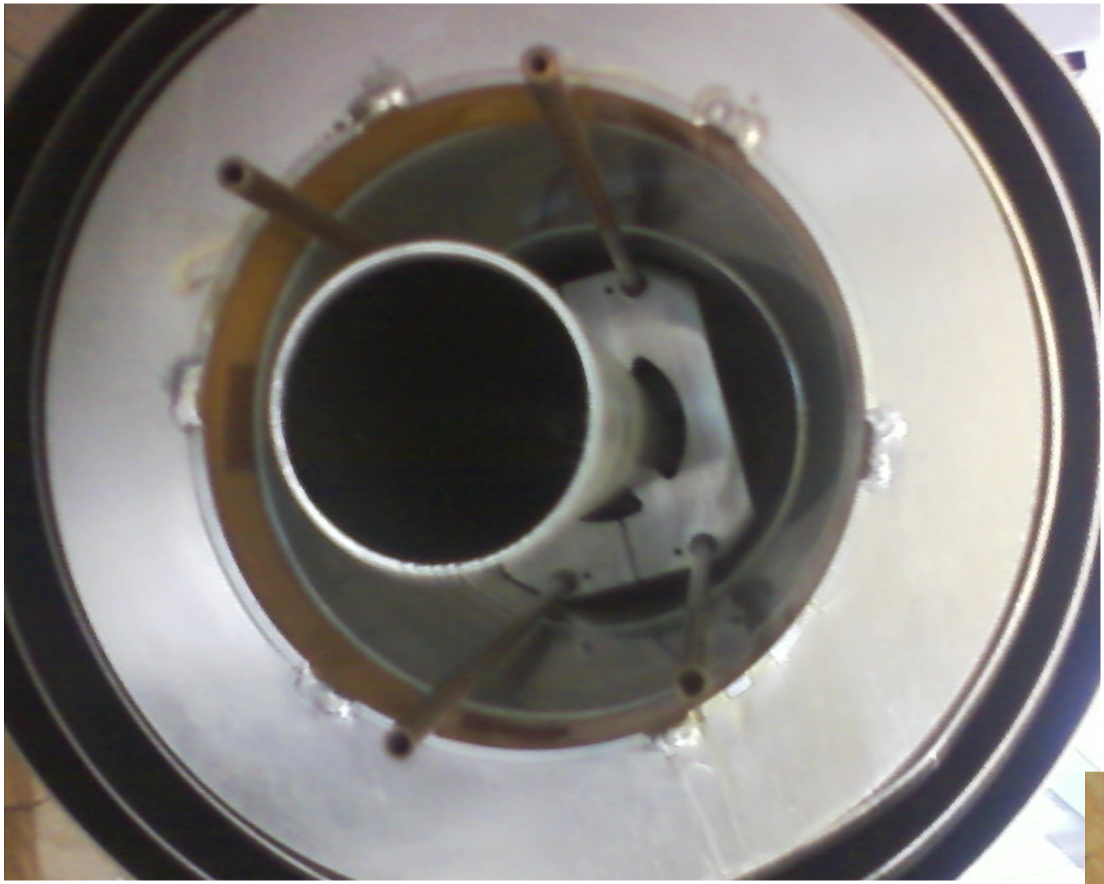
Baseline approach:

"Non-magnetized" – means no strong magnetic field to guide electron beam and in cooling section

1) "as is" - present FNAL's set-up with small magnetic field on the cathode (100G) and in cooling section (100G) (+ undulators).

2) Zero magnetic field on the cathode and zero magnetic field in cooling section - short solenoids to counteract space-charge defocusing every 2 meter (+undulators).

Electron kinetic energy, MeV	0.9-2.8 (4.9)
DC current, mA	50-100
RMS momentum spread	< 0.0004
RMS transverse angles, mrad	< 0.2
Undulator field B_u, G	3
Undulator period: λ_u, cm	8
Length of cooling section L_{cool} per ring, m	10



If we go with zero magnetic field approach, then we do not change present 5″ beam pipe in RHIC.
But this approach requires several other questions to be addressed.

If approach with magnetic field:
What is maximum allowable pipe diameter for baking to fit into solenoids?
R_solenoid=6.9cm?
Can we do R=3.75cm (3″ pipe)?
R=5cm (4″ pipe)?

If we go with "solenoids" option:

1. **M. Mapes – both 3″ pipe and 4″ pipe will work for baking.**
2. **BPM's:**

- **3″ pipe (R=3.8cm) will allow BPMs to be placed between vacuum chamber and solenoids (R=6.9cm); one can use FNAL's design of BPM's; no need to modify gap between solenoids. But will need to modify RHIC lattice for cooling section significantly (from 100m to 30m beta-function).**
- **4″ pipe requires putting BPM's in the gap; requires redesigning of the gap, adding additional corrector coils.**

If we go without "solenoids" options:

- Requires solutions for control of electron angles in cooling section

Baseline for cooling section:

No long solenoids?

Would allow to keeping present 5″ RHIC beam pipe.

Requires addressing an issue of ion clearing.

It looks like an issue of secondary ions can be addressed, but cooling section without solenoids may not work for RHIC after all.

Secondary ions

No magnetic field:

Secondary ions need to be controlled to such level that one does not have over focusing.

- For RHIC, this could be not a problem since positive charge of ion beam is larger than effective charge of electron beam – will kick secondary ions out.
- Recent experiment at FNAL showed that ions can be cleared by interrupting electron beam for 2 micro seconds (with 15Hz rate).

With magnetic field:

Busch's theorem prevents electron beam from being over focused in cooling section.

$$Ba_e^2\Big|_{cooler} = Ba_e^2\Big|_{cathode}$$

Problem of over focusing from ion beam

Although, it looks like problem of secondary ions can be addressed, the problem of over focusing remains:

For lowest energy point:

Peak current of ions is 0.4A

Electron current: 0.05-0.1A

So, instead of defocusing in the cooling section due electron beam space charge we have focusing of electron beam by ion beam.

Such focusing is weak. But for cooling, resulting angles exceed requirement already after 4 meters of interaction.

Solution?

Back to FNAL design with solenoids?

Problem of over focusing (continued)

One can increase Electron current to 0.4A.

But for higher energies, when ion current could be 1A this would require increase of electron current to 1A.

This creates problems:

1. Loss on recombination becomes significant. Will require use of undulators. Will complicate cooling section design + additional significant cost.
2. Transport of high-current electron beam through the Pelletron without magnetization near the cathode could be a problem.

Baseline for cooling section?

With magnetization:

Pros:

1. working approach
2. "as is" from FNAL, a lot of experience available
3. minimum modifications will be needed

Cons:

1. will require smaller beam pipe
2. some redesigning of gap between solenoids may be needed
3. looks complicated

Without magnetization:

Pros:

1. looks simpler

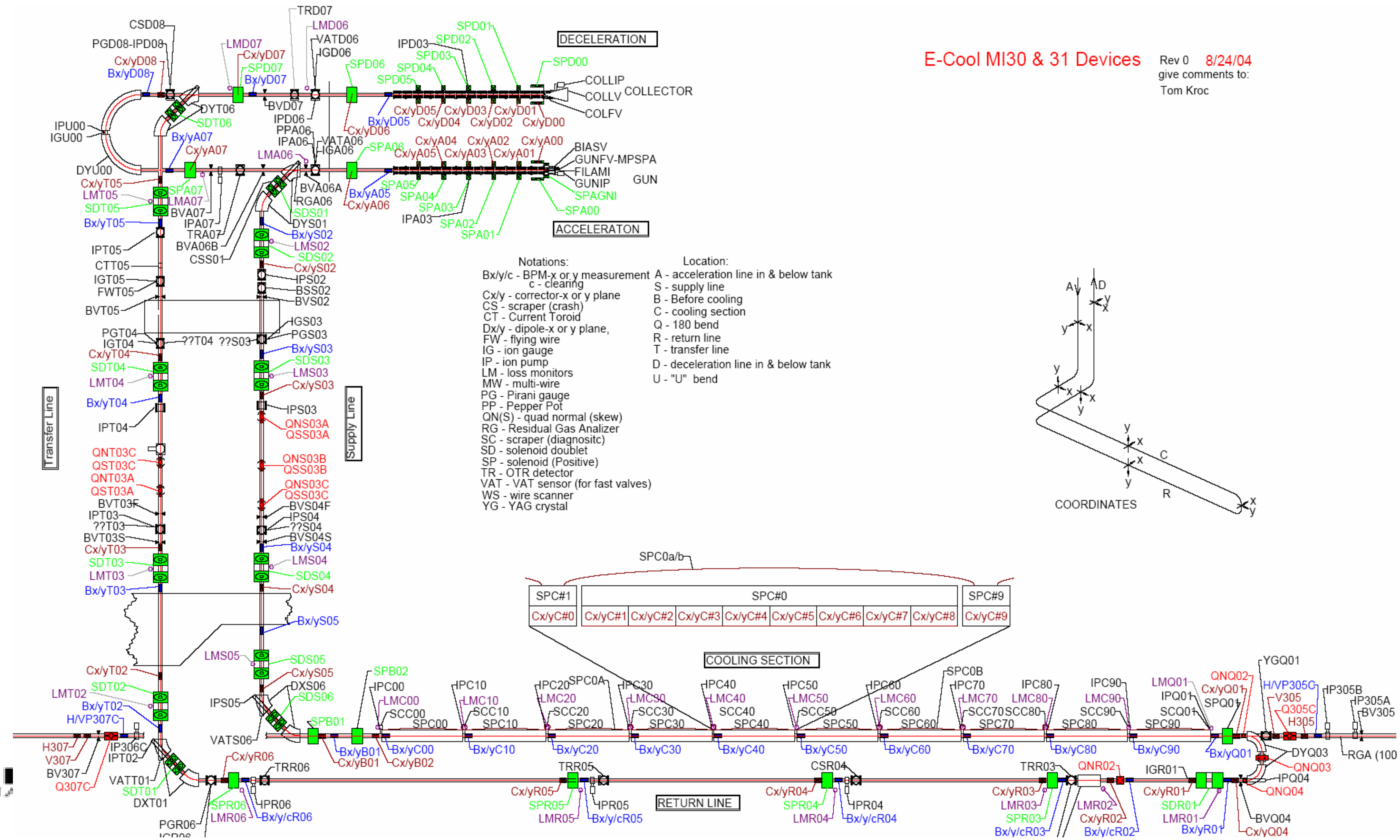
Cons:

1. approach which was not demonstrated
2. problem of over focusing
3. will require high e-current
4. problem of recombination
5. undulator design + cost
6. significant design complications
7. problem of high-current transport through the Pelletron without magnetization

Some engineering questions

1. Can we use Recycler magnets from 90 degree bends? Quality of field at low energies is an issue.
2. Can we use Recycler's feedback system based on NMR or the field is too low for NMR?
3. Is present 180 ("U-turn") degree turn satisfactory for preserving quality of electron beam from one section to another?
4. Design of undulator for recombination suppression.
5. What engineering modifications to present cooling sections are needed to accommodate undulators?
6. Is required vacuum chamber size in cooling section compatible with present design of cooling section with many things located in between vacuum chamber and solenoids? Issue: vacuum chamber needs to be increase due to large ion beam size at low energy which reduces the space to the inner board of the solenoids.

Diagnostics



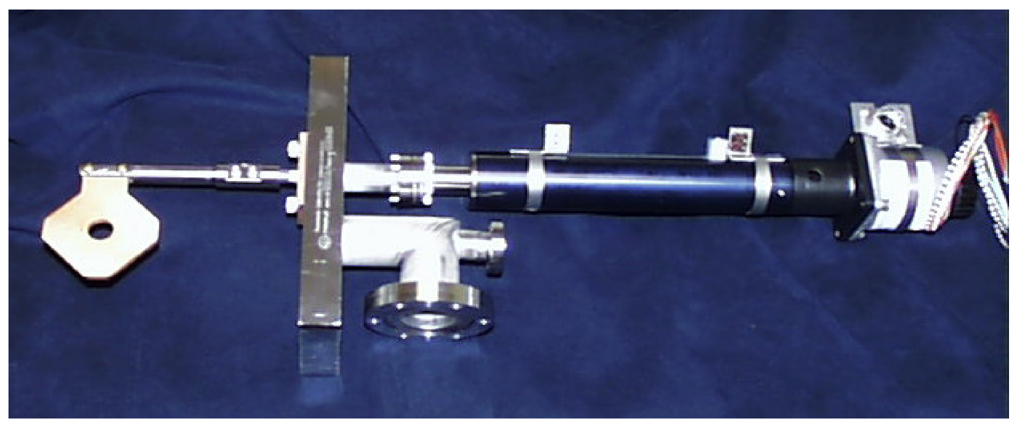
New diagnostics for cooling section

- **Hardware modification for 11 BPM's will be needed in any case, since FNAL's BPM's in cooling section are for 2″ beam pipe.**

If we go with 3″ pipe (R=3.8cm), can probably use existing FNAL's design of BPM's for 3″ pipe.

- **Modification of scrapers**

15 mm hole



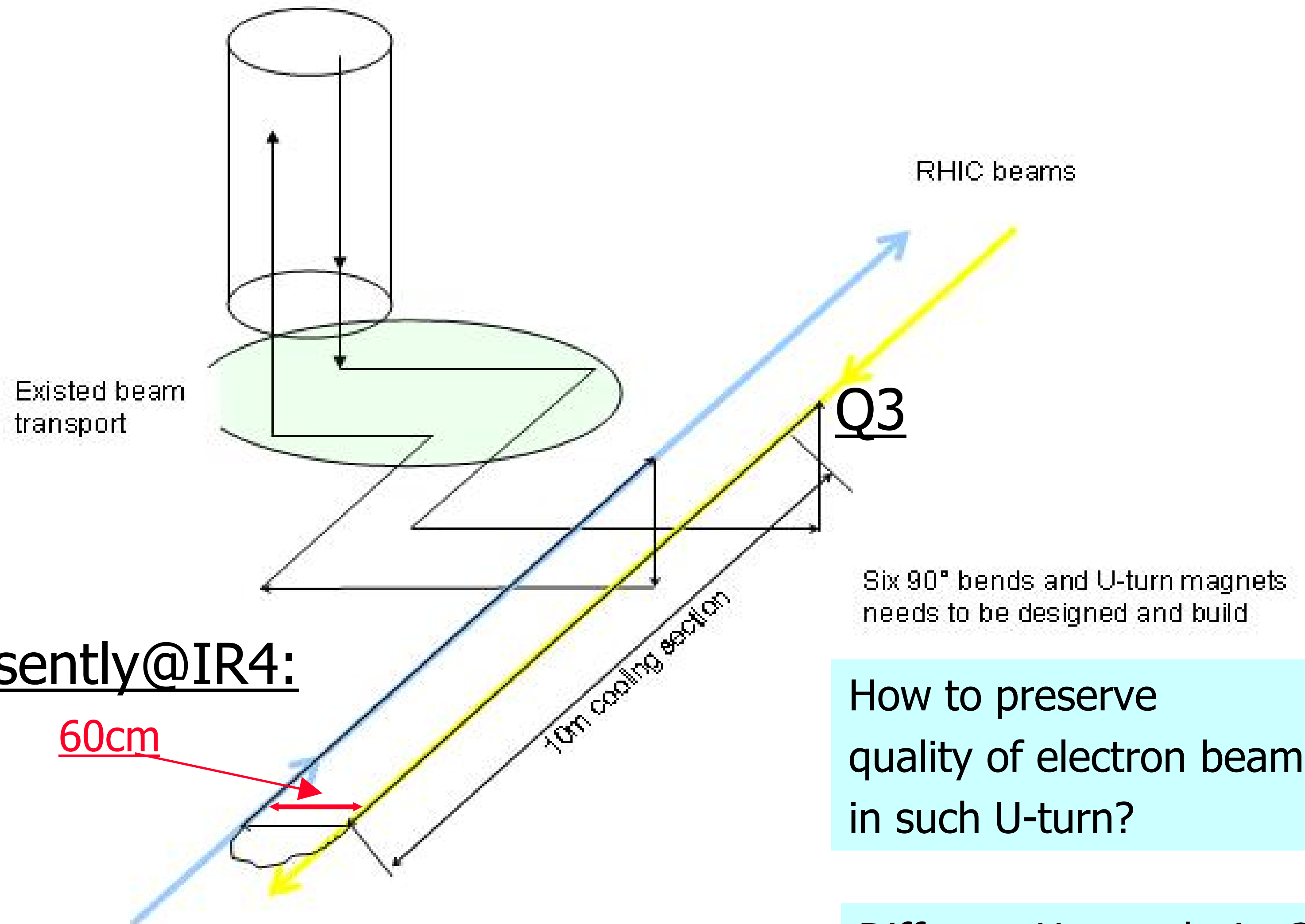
Our beam is about 2cm wide. One more argument for larger 4″ pipe (R=5cm) and moving BPM's in the gap.

Some physics questions

- Besides some technical modifications, this will be the first cooler to cool directly beams under collisions (many interesting consequences).

1. Quality of electron beam transport at lowest energy, including turn around of electron beam between cooling section.
2. Estimates of various contributions to angular budget in cooling section in all energy range of interest.
3. Requirement on energy control in both RHIC rings.
4. Requirement of beam alignment in all energy range.
5. Do we need undulators for recombination suppression?
6. Maximum size of electron beam in cooling section? Cooling with large electron beam on center or small beam off-center?
7. Simulations. Gun and Pelletron: SAM/UltraSAM (used at FNAL); TRAK (used at BNL). PARMELA or OPTIM for cooler optics and matching,

Presently@IR4:



How to preserve quality of electron beam in such U-turn?

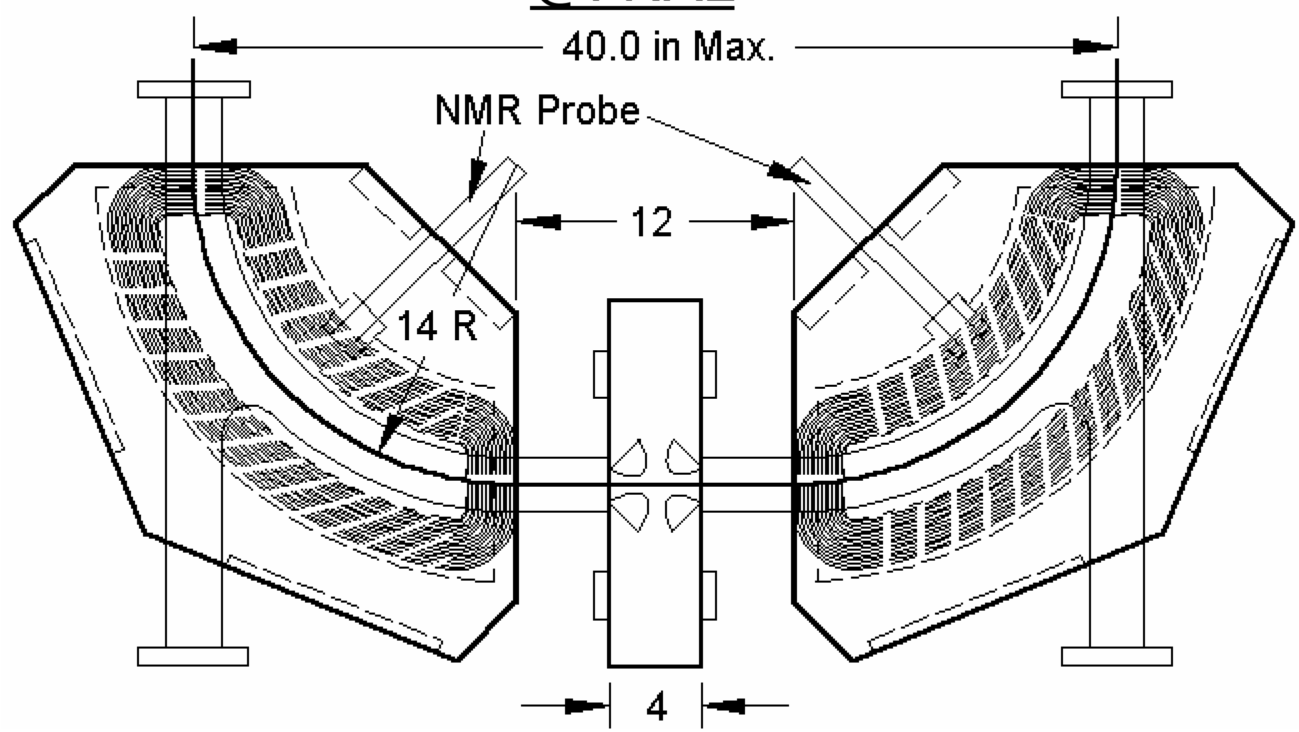
Different U-turn design?

U-bend at FNAL

@IR4: 24in (Preliminary design D.Kayran, J.Brodowski)

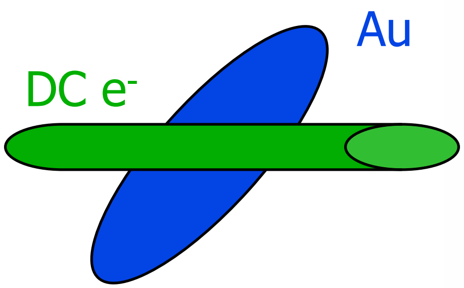
@IR12: 28in

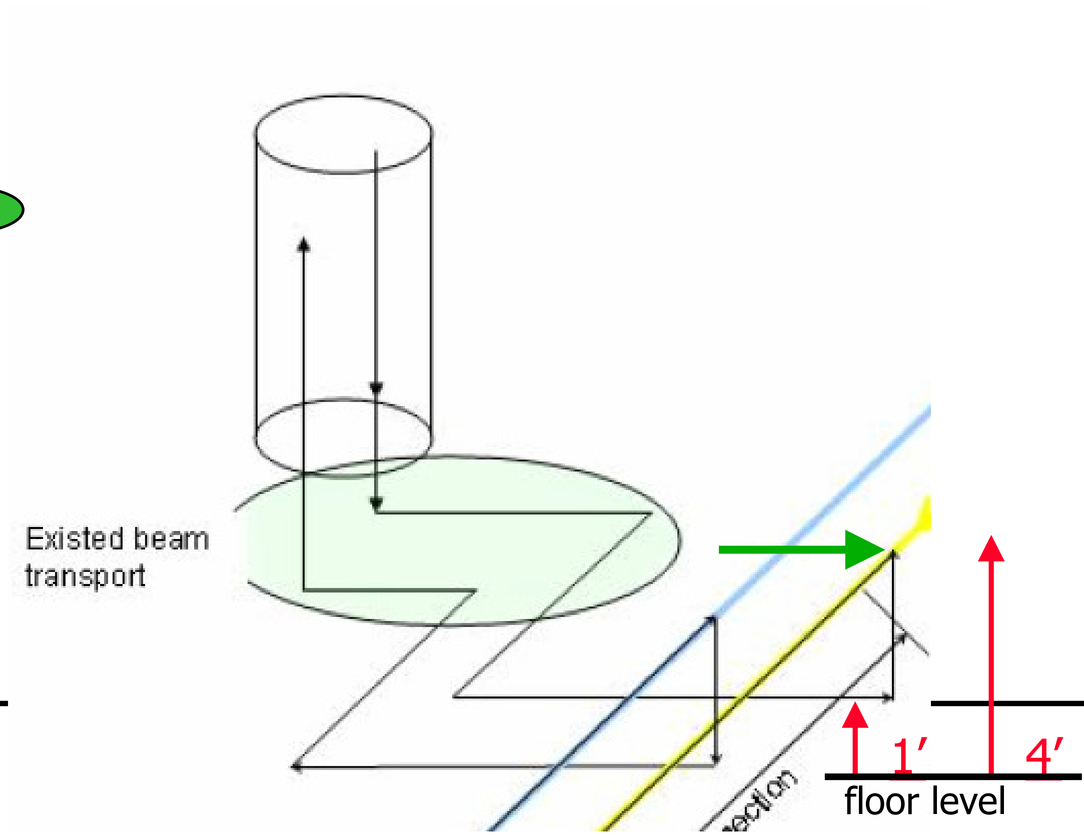
@FNAL



Minimizing number of bends

- **Presently, the plan is to go with DC electron beam around one ion beam pipe to inject into the other.**
- **Can we consider going right through the ion beam?**





BROOKHAVEN NATIONAL LABORATORY

RHIC

Electron DC beam going through ion bunches

- **Effect can be estimated as beam-beam at 90 degree angle.**
- **It looks like no effect on horizontal motion, while effect on longitudinal motion is negligible.**

Should we consider it as baseline approach?

Coming directly at the level of RHIC beams: 4'

Going through ion beam with 90 degree angles?

Going through with a smaller angle (add negligible horizontal tune shift)?

Major "near-term" tasks

1. Transport of electron beam at lower energies; design of bending magnets; evaluating needed control of field quality.
2. Design of turn around (U-turn) of electron beam between cooling sections. Checking preservation of electron beam quality with additional bends, lowest energy, etc.
3. Electron cooler optics. Electron beam. Ion beam.
4. Careful consideration of "angular budget" in the cooling section from various effects in full energy range of interest.
5. Interaction of electron and ion beams.
6. Undulators "to be or not to be?"
7. Cooling section and diagnostics.